CHAPTER 1

INTRODUCTION

Section I. General

1-1. Purpose. This manual presents guidance for the hydraulic design analyses of reservoir outlet works facilities. Although primarily prepared for the design of reservoir outlet works, the theory, procedures, and data presented are generally applicable to the design of similar facilities used for other purposes. Studies pertinent to the project functions and their effects on the hydraulic design of outlet works are briefly discussed. Where appropriate, special design guidance is given for culverts, storm drains, and other miscellaneous small structures. Procedures are generally presented without details of theory since these details can be found in many hydraulic textbooks. However, some basic theory is presented as required to clarify presentation and where the state of the art is limited in textbooks. Both laboratory and prototype experimental test results have been correlated with current theory in the design guidance where possible.

1-2. Applicability. This manual applies to all OCE elements and all field operating activities having responsibilities for the design of civil works projects.

1-3. References.

a. National Environmental Policy Act (NEPA), PL 9-190, Section 102(2)(c), 1 Jan 1970, 83 Stat 853.

b. TM 5-820-4, Drainage for Areas Other than Airfields.

c. ER 1110-1-8100, Laboratory Investigations and Materials Testing.

d. ER 1110-2-50, Low Level Discharge Facilities for Drawdown of Impoundments.

e. ER 1110-2-1402, Hydrologic Investigation Requirements for Water Quality Control.

f. ER 1110-2-2901, Construction Cofferdams.

g. ER 1110-2-8150, Investigations to Develop Design Criteria for Civil Works Construction Activities.

h. EM 1110-2-1601, Hydraulic Design of Flood Control Channels (Changes 1-2).

i. EM 1110-2-1603, Hydraulic Design of Spillways (Change 1).

j. EM 1110-2-2400, Structural Design of Spillways and Outlet Works.

k. EM 1110-2-2901, Design of Miscellaneous Structures, Tunnels.

l. EM 1110-2-2902, Conduits, Culverts & Pipes (Changes 1-2).

m. EM 1110-2-3600, Reservoir Regulation (Changes 1-3).

n. Hydraulic Design Criteria (HDC) sheets and charts. Available from: Technical Information Center, U. S. Army Engineer Waterways Experiment Station (WES), P. O. Box 631, Vicksburg, MS 39180.

o. Conversationally Oriented Real-Time Program Generating System (CORPS) computer programs. Available from: WESLIB, U. S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180, and from several CE computer systems.

Where the above-listed references and this manual do not agree, the provisions of this manual shall govern.

1-4. <u>Bibliography.</u> Bibliographic items are indicated throughout the manual by numbers (item 1, 2, etc.) that correspond to similarly numbered items in Appendix A. They are available for loan by request to the Technical Information Center Library, U. S. Army Engineer Waterways Experiment Station, P. O. Box 631, Vicksburg, MS 39180.

1-5. <u>Symbols.</u> A list of symbols is included as Appendix B, and as far as practical, agrees with the American Standard Letter Symbols for Hydraulics (item 3).

1-6. <u>Other Guidance and Design Aids.</u> Extensive use has been made of <u>Hydraulic Design Criteria (HDC)</u>,[n] prepared by WES and OCE. Similarly, data and information from Engineer Regulations and special reports have been freely used. References to <u>Hydraulic Design Criteria</u> are by HDC chart number. Since HDC charts are continuously being revised, the user should verify that the information used is the most up-to-date guidance. Applicable HDC charts and other illustrations are included in Appendix C to aid the designer. References to specific project designs and model studies are generally used to illustrate the structure type, and the dimensions are not necessarily the recommended dimensions for every new project. The WES Automatic Data Processing Center (ADPC) Computer Program Library (WESLIB) provides time-sharing computer services to CE Divisions and Districts. One such service is the Conversationally Oriented Real-Time Program-Generating System (CORPS) that especially provides the noncomputer-oriented or noncomputer-expert engineer a set of proven engineering applications programs, which he can access on several different computer systems with little or no training. (See item 54 for instructions on use of the system and a partial list of available programs. Updated lists of programs can be obtained through the CORPS system.) References to available programs that are applicable to the design of reservoir outlet works are noted in this manual by the CORPS program numbers.

1-7. WES Capabilities and Services. WES has capabilities and furnishes services in the fields of hydraulic modeling, analysis, design, and prototype testing. Recently, expertise has been developed in the areas of water quality studies, mathematical modeling, and computer programming. Procedures necessary to arrange for WES participation in hydraulic studies of all types are covered in ER 1110-1-8100.[c] WES also has the responsibility for coordinating the Corps of Engineers hydraulic prototype test program. Assistance during planning and making the tests is included in this program. (See ER 1110-2-8150.[g])

1-8. Design Memorandum Presentations. General and feature design memoranda should contain sufficient information to assure that the reviewer is able to reach an independent conclusion as to the design adequacy. For convenience, the hydraulic information, factors, studies and logic used to establish such basic outlet works features as type, location, alignment, elevation, size, and discharge should be summarized at the beginning of the hydraulic design section. Basic assumptions, equations, coefficients, alternative designs, consequences of flow exceeding the design flow, etc., should be complete and given in appropriate places in the hydraulic presentation. Operating characteristics and restrictions over the full range of potential discharge should be presented for all release facilities provided.

1-9. Classification of Conduits. Two broad classifications of reservoir outlet works facilities are discussed in this manual: concrete gravity dam and embankment dam facilities. Outlet works through concrete gravity dams will be called sluices while those through embankment dams will be called conduits and/or tunnels.

a. Concrete Gravity Dams. Generally, sluices that traverse through the masonry of concrete gravity dams have rectangular cross sections and are short in comparison with conduits through embankment dams of comparable height. Use of a number of small sluices, at one or more elevations, provides flexibility in flow regulation and in quality of water released downstream. Sluices are controlled by gates at the upstream face and/or by gates or valves operated from a gallery in the interior of the dam. Sluices are usually designed so that the outflow discharges onto the spillway face and/or directly into the stilling basin. When sluices traverse through nonoverflow sections, a separate energy dissipator must be provided. Arch dams, multiple arch dams, and hollow concrete dams are less common; and although the outlet works design may require special features, the same hydraulic principles are applicable.

b. Embankment Dams. Conduits and/or tunnels for embankment dams may have circular, rectangular, horseshoe, or oblong cross sections and their length is primarily determined by the base width of the embankment. Due to the greater length, it is usually more economical to construct a single large conduit than a number of small conduits. Conduits should be tunneled through the abutment as far from the embankment as practicable, or placed in an open cut through rock in the abutment or on the valley floor. Gates and/or valves in an intake tower in the reservoir, in a central control shaft in the abutment or embankment, or at the outlet portal are used to control the flow. Generally, placement of the control device at the outlet portal should be avoided when the conduit passes through the embankment due to the inherent dangers of a possible rupture of a conduit subject to full reservoir head. Diversion during construction or reservoir evacuation requirements, especially on large streams, may govern the size and elevation of the conduit(s). Foundation conditions at the site may also govern the design. (See EM 1110-2-2901[k] and EM 1110-2-2902.[l])

Section II. Project Functions and Related Studies

1-10. General. Project functions and their overall social, environmental, and economic effects greatly influence the hydraulic design of outlet works. Optimization of the outlet works hydraulic design and operation requires an awareness by the designer of the reliability, accuracy, sensitivity, and possible variances of the data used. The ever-increasing importance of environmental considerations requires that the designer maintain close liaison with many disciplines to be sure environmental and other objectives are satisfied in the design. General project functions and related design considerations are briefly discussed in the following paragraphs.

a. Functions.

(1) Flood Control. Flood control outlets are designed for relatively large capacities where close regulation of flow is less important than are other requirements. Although control of the outflow by gates is usually provided, the conduits may be ungated, in which case the reservoir is low or empty except in time of flood. When large discharges must be released under high heads, the design of gates, water passages, and energy dissipator should be carefully developed. Multilevel release provisions are often necessary for water quality purposes.

(2) Navigation. Reservoirs that store water for subsequent release to downstream navigation usually discharge at lower capacity than flood control reservoirs, but the need for close regulation of the flow is more important. The navigation season often coincides with the season of low rainfall, and close regulation aids in the conservation of water. Outlet works that control discharges for navigation purposes are required to operate continuously over long periods of time. The designer should consider the greater operation and maintenance problems involved in continuous operation.

(3) Irrigation. The gates or valves for controlling irrigation flows are often basically different from those used for flood control due to the necessity for close regulation and conservation of water in arid regions. Irrigation discharge facilities are normally much smaller in size than flood regulation outlets. The irrigation outlet sometimes discharges into a canal or conduit rather than to the original riverbed. These canals or conduits are usually at a higher level than the bed of the stream.

(4) Water Supply. Municipal water supply intakes are sometimes provided in dams built primarily for other purposes. Such problems as future water supply requirements and peak demands for a municipality or industry should be determined in cooperation with engineers representing local interests. Reliability of service and quality of water are of prime importance in water supply problems. Multiple intakes and control mechanisms are often installed to assure reliability, to enable the water to be drawn from any selected reservoir level to obtain water of a desired temperature, and/or to draw from a stratum relatively free from silt or algae or other undesirable contents. Ease of maintenance and

repair without interruption of service is of primary importance. An emergency closure gate for priority use by the resident engineer is required for water supply conduits through the dam.

(5) Power. Power penstocks are not within the scope of this manual. However, if reservoir outlets are to be located in the vicinity of the power plants and switchyards, conduit outlets and stilling basins should be designed so as not to cause any undesirable eddies, spray, or wave action that might jeopardize turbine operation. Power tunnels or penstocks may be used for flood control and/or diversion of the stream during construction of the dam and in such cases the discharge capacity may be determined by the principles outlined in this text.

(6) Low-Flow Requirements. Continuous low-flow releases are required at some dams to satisfy environmental objectives, water supply, downstream water rights, etc. To meet these requirements multilevel intakes, skimmer weirs, or other provisions must be incorporated separately or in combination with other functions of the outlet works facility. Special provisions for these purposes have been incorporated in concrete gravity dam nonoverflow sections. Embankment dams with mid-tunnel control shafts also require special considerations for low-flow releases.

(7) Diversion. Flood control outlets may be used for total or partial diversion of the stream from its natural channel during construction of the dam. Such use is especially adaptable for earth dams (see EM 1110-2-2901[k] and ER 1110-2-2901[f]).

(8) Drawdown. Requirements for low-level discharge facilities for drawdown of impoundments are given in ER 1110-2-50.[d] Such facilities may also provide flexibility in future project operation for unanticipated needs, such as major repairs of the structure, environmental controls, or changes in reservoir regulation.

(9) Multiple Purpose. Any number of purposes may be combined in one project. The designer should study carefully the possible economics of combining outlets into a single structure for multiple use.

b. Related Studies.

(1) Environmental. The general philosophy and guidance for preservation, mitigation, and/or enhancement of the natural environment have been set forth (item 96). Many scientific and engineering disciplines are involved in the environmental aspects of hydraulic structures.

Some studies influencing the outlet works design are briefly discussed below. Pertinent data from these studies should be presented in the design memorandum. The designer should have a working knowledge of these data and their limitations.

(a) Fish and Wildlife. Outlet works design and operation can maintain, enhance, or damage downstream fish and wildlife. Flow releases not compatible with naturally seasonable stream quantity and quality can drastically change aquatic life. These changes may be beneficial or may be damaging, such as adverse temperatures or chemical composition, or nitrogen supersaturation (item 86). Information from fish and wildlife specialists on the desired stream regimen should be obtained and considered in the design. Downstream wildlife requirements may fix minimum low-flow discharges. The water quality presentation should include summary data on requirements and reference to source studies.

(b) Recreation. Recreation needs including fishing, camping, and swimming facilities, scenic outlooks, etc., should be considered in the design of energy dissipators and exit channels. These requirements are usually formulated by the planning discipline in cooperation with local interests. To accomplish the desired objectives, close cooperation between the hydraulic and planning engineers is required. Special consideration should be given to facilities for the handicapped, such as wheelchair ramps to fishing sites below stilling basins. Safety fences for the protection of facilities and the public are important. Appreciable damage to stilling basins has resulted from rocks thrown in by the public. The hydraulic engineer should recognize the need for such things as: (1) nonskid walks and steps with handrails designed to protect the elderly and young children; (2) periodic lowering of reservoir levels and flushing of stagnant pools downstream for vector control (mosquitoes, flies, etc.); (3) elimination of construction scars resulting from borrow pits, blasting, land clearing, etc; and (4) maintenance of relatively constant pool levels for reservoir recreation activities.

(c) Water Quality. An awareness of maintaining and/or enhancing the environment within the past decade has brought into existence a relatively new and expanded art of reservoir hydrodynamics. Until recently, the study of reservoir hydrodynamics has been limited to a few prototpye vertical temperature gradients and recognition of the seasonal inversions accompanying the fall surface water cooling. However, environmental considerations of today have necessitated the development of preproject capability for prediction of the expected seasonal reservoir stratification and circulation to permit construction and operation of outlet works designed to meet storage and outflow regimes needed for the reservoir and downstream environment. Reservoir hydrodynamic studies may be done by other than the hydraulic designer (such as the hydrologic engineers) and they would specify the withdrawal requirements (quantity, elevation, etc.). The hydraulic engineer then designs the outlet works to meet these requirements. However, the hydraulic designer furnishes some of the information for the hydrologic studies.

(2) Foundations. In concrete dams, foundation conditions have little if any effect upon the hydraulic design of sluices. However, the hydraulic design of outlet works for embankment dams can be appreciably affected by foundation conditions. The conduit shape and control tower location are usually fixed primarily by foundation, structural, and construction considerations in addition to hydraulic requirements. Energy dissipator and outlet channel designs for either sluices or embankment dam outlets are sometimes influenced by local foundation conditions. Foundation information of interest to the hydraulic designer includes: (a) composition and depth of overburden, (b) quality of underlying rock, and (c) quality of exposed rock. In addition, side-slope stability is of considerable importance in the design of riprap protection. Outflow stage change rates are required for bank stability design. Sufficient foundation data and/or reference to its source should be included or referred to in the hydraulic presentation to substantiate the energy dissipator and exit channel design.

(3) Environmental Impact Statements. Section 102(2)(c) of the National Environmental Policy Act (NEPA)[a] requires detail documentation in the project design memoranda on the impact of the planned project on the environment. The hydraulic engineer may be required to cooperate in the preparation of impact statements. An analysis of 234 Corps of Engineers environmental impact statements on various projects is given in IWR Report No. 72-3 (item 122). This report can be used as a guide as to the type of material needed and format to be used in developing the statements. Basic to the environmental statements are studies made to define the preproject and project functions and their effects on the environment. In most cases the effect of each project function must be set forth in detail. A recent publication by Ortoano (item 87) summarizes the concepts involved and presents examples relative to water resources impact assessments. Presentation of the hydraulic design in design memoranda must identify environmental requirements and demonstrate how these are satisfied by the hydraulic facility.

(4) Project Life. Two factors in the life of a project of concern to the hydraulic engineer in the design of outlet works are

(a) downstream channel aggradation and degradation, and (b) structural deterioration.

(a) Channel Aggradation and Degradation. In many rivers determination of the dominant factors causing bed shaping action like degradation and aggradation is difficult. Changes in the hydrographic characteristics caused by a dam can result in undesirable changes in the elevation of the riverbed. Degradation, or lowering of the riverbed, immediately downstream of a dam may threaten the integrity of the structure. Removal of all or part of the sediment by the reservoir may induce active erosional attack downstream. Similarly, although the total annual sediment transport capacity of the river will drop significantly, the sediment supply by downstream tributaries will be unaltered and there may be a tendency for the riverbed to rise. This channel aggradation can increase the flood hazards from downstream tributaries and may cause reduction in outlet works allowable releases. Resulting tailwater level changes can also adversely affect the stilling basin performance.

(b) Concrete Deterioration. Excessive invert erosion of outlet structures has occurred where sands, gravel, and construction debris have passed through conduits used for diversion during extended periods of low reservoir stages. Construction of a submerged sill upstream of the intake to trap the debris should be considered where this condition is likely to occur. Special materials or liners may be helpful in preventing invert erosion in extremely cold climates where deterioration of the conduit interior from freezing-and-thawing cycles is possible.